

EFFECTIVE REPAIR AND MAINTENANCE STRATEGIES FOR PARKING STRUCTURES

BY PAWAN R. GUPTA AND K. NAM SHIU

Parking structures provide efficient parking for office buildings, shopping centers, universities, airports, train stations, bus stations, and hospitals in both urban and suburban settings. Figure 1 shows a large parking structure that serves a large office complex in Irvine, CA. Parking structures can be constructed of cast-in-place concrete, precast concrete, structural steel, or a combination of these basic types of structural systems (Fig. 2).



Fig. 1: Typical parking structure

Because parking structures typically require long spans for efficient parking layout, post-tensioned concrete systems are common in the design of cast-in-place parking structures. Elevated parking structures are typically designed without ventilation or air-conditioning as open structures with typically 40% of the perimeter being open.

Because parking structures are typically open, they experience harsher exposure conditions as compared to most buildings. Temperature extremes, dynamic loads, and deicer attacks are potentially destructive to all parking facilities. Premature deterioration, such as scaling, spalling, cracking, and leaking can reduce the integrity of exposed concrete surfaces, especially floor slabs (Fig. 3). Parking garage maintenance is typically not considered to be a priority by owners and operators and is often deferred. Sometimes, this can lead to premature deterioration that can impair the structural system's integrity and become very costly to repair. Timely corrective and preventive maintenance action is needed to reduce the impact and cost of structural deterioration.

SERVICE LIFE AND LIFE-CYCLE COST OF PARKING STRUCTURES

The impact of deterioration on repair costs and service life of the parking structure is demonstrated by Fig. 4. Because the loads and environmental conditions in enclosed buildings do not change rapidly, most buildings deteriorate slowly over time. This is shown by the normal deterioration curve. Parking structures that are open and subjected to thermal movement and dynamic loads follow the accelerated rate of deterioration curve. Initially, in the early stage of their service life, parking structures follow the normal deterioration curve; however, after they have been in use for a few years, the rate of deterioration accelerates. This is caused by repeated exposure of the structure to temperature changes and dynamic loads, combined with exposure to moisture and chlorides that promotes rusting of the embedded reinforcing steel, causing further cracking and spalling of the concrete. This is shown by Curve A-B. If timely repairs are not conducted, the structure would continue to deteriorate at an



(a) Cast-in-place long span post-tensioned (b) Cast-in-place flat slab post-tensioned



(c) Precast double tee beams and precast light walls (d) Steel frame with concrete on metal deck

Fig. 2: Common structural systems for parking structures

accelerated rate, causing the structure to lose integrity and become unsafe. This is represented by Curve B-C. Effective repair strategies address the existing deterioration and reduce the ingress of moisture and chlorides into the structure, thus bringing the structure closer to the normal deterioration rate. This is represented by vertical lines A-A' and B-B'. Repairs that are performed at early stages of deterioration cost considerably less and are more effective (A-A') as compared to repairs that are performed later in the life of the structure (B-B').

Figure 5 shows the relationship between life-cycle cost and restoration interval. As a parking structure ages, effective and timely restoration strategies can reduce the overall life-cycle cost of the structure. There is an optimal interval when the parking structure should undergo maintenance and repairs. If repairs are conducted too frequently, the total costs of maintenance can add up significantly. On the other hand, if repairs are delayed too long beyond the optimal point, repair costs can also increase significantly as a result of deferred repair and maintenance. An effective asset management plan for a parking structure would include an optimal interval for repairs and maintenance to minimize the overall life-cycle cost of the parking structure. The interval and extent of repairs varies based a number of factors, including type of construction, age of the structure, location, use, and existing deficiencies.

MAINTENANCE PROGRAM

A comprehensive maintenance program requires that an annual budget be established. This budget should begin on the first day of operation and account for costs such as operating expenses, routine and preventative maintenance, and structural repairs, rehabilitation, and restoration. The two main components of effective repair planning are routine and preventative maintenance, as well as structural repairs, rehabilitation, and restoration.

ROUTINE AND PREVENTATIVE MAINTENANCE

Routine and preventative maintenance include many activities that can be completed either quarterly or annually by in-house personnel. As a minimum, a routine walk-through inspection should be conducted at least once a year. This should be in conjunction with a washdown of the structure, so that any active leakage can be noted and its source identified. Areas of concern such as cracks, leaks, joint sealant failures, and general surface deterioration can be recorded on plan sheets for each floor. Resource materials have been published by professional organizations such as the National Parking Association (NPA) and Prestressed/Precast Concrete Institute (PCI) on how to perform routine and preventative maintenance of parking structures.^{1,2}



Fig. 3: Common types of deterioration in parking structures

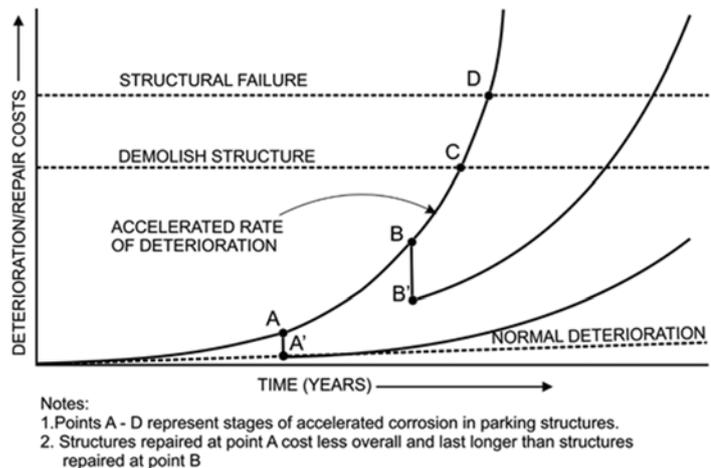


Fig. 4: Parking structure deterioration curve⁵

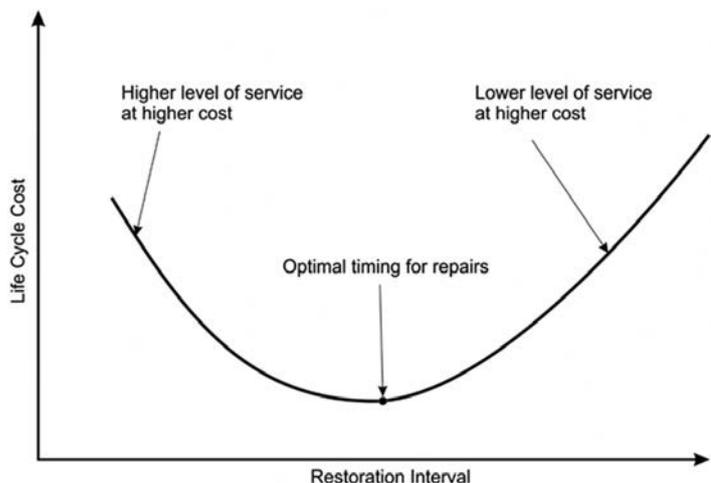


Fig. 5: Life-cycle cost of a parking structure⁶

ANNUAL STRUCTURAL CHECKLIST

PARKING STRUCTURE NAME

INSPECTOR

OWNER

DATE

CITY, STATE

FLOORS

- When was the last floor sealer application? (Typically applied every 3 to 5 years)
- Are there rips, tears, debonded areas, or signs of embrittlement in the traffic topping?
- Are there cracks in the floor slab? If yes, where are they located and how wide are they?
- Are there signs of leaking?
- Any spalls or delaminations? If yes, how big and where are they located?
- Has chloride ion content testing been performed this year?

BEAMS AND COLUMNS

- Are there cracks? If yes, are they vertical or horizontal and how wide?
- Are there any signs of leaking?

STAIR/ELEVATOR TOWERS

- Are there any signs of a leaking roof?
- Are there any cracks in the exterior brick?
- Are there any cracks in the mortar joints?

NOTES AND CORRECTIVE ACTION NEEDED:

JOINTS

- Are there any signs of leaking, loss of elasticity or separation from adjacent surfaces?
- Expansion joints
- Control joints
- Construction joints
- Tee-to-tee joints

ARCHITECTURAL SEALANTS

- Are there any signs of leaking, loss of elasticity, or separation from adjacent surfaces?
- Between windows and doors
- In block masonry
- Exterior sealants
- Concrete walks, drives, and curb landings

EXPOSED STEEL

- Is there any exposed steel? If yes, where is it located and is it rusted?

MASONRY

- Are there any cracks in the brick?
- Are there any cracks in the mortar?
- Are there any brick spalls? If yes, where are they located and how big are they?

NOTES AND CORRECTIVE ACTION NEEDED:

BEARING PADS

- Are bearing pads squashed, bulging, or out of place? If yes, where?

After answering the above questions, please consult a qualified engineer to discuss your answers.

NOTES AND CORRECTIVE ACTION NEEDED:

Fig. 6: Typical structural checklist for parking structures

In-house personnel should use checklists to record observations during the routine and preventative maintenance walkthrough. A sample structural checklist for routine inspection of parking structures is included as Fig. 6. Photos of items that need corrective actions should be taken and discussed with a qualified restoration engineer with corrective measures implemented in a timely manner.

STRUCTURAL REPAIRS, REHABILITATION, AND RESTORATION

Every 5 years or whenever structural problems are suspected, a restoration engineer should conduct a comprehensive condition appraisal.^{3,4} Depending on age and existing condition of the structure, the appraisal may include either a quick walkthrough review or a more detailed assessment that includes nondestructive or partially destructive testing and laboratory material testing of concrete to establish baseline performance and better evaluate potential problems. Based on the appraisal, the restoration engineer can provide a prioritized list of repair recommendations and an opinion of probable construction costs to implement the corrective measures for extending the useful service life of the structure. Depending on the age of the structure, stage of deterioration, and type of structure, common repair items could include concrete restoration, installation/repair of waterproofing membrane, routing and

sealing of cracks, control joint and other sealants, expansion joint replacement, and painting of exposed metals and concrete surfaces.

If significant damage to the existing concrete, reinforcing bars, or post-tensioning system is identified, a more in-depth restoration program may be needed to bring the structure to the normal deterioration curve. Depending on the budget constraints of the owner, it may be possible to phase the major structural repairs over a period of time. A specialty contractor experienced in waterproofing/structural repairs of parking structures should be used to conduct the structural repairs in the parking structure.

ANNUAL MAINTENANCE BUDGET

A question that is commonly asked by owners and operators is, "How much should we budget for annual parking structure maintenance?" The annual maintenance cost depends on a number of factors, including type of construction, age of the structure, location of the structure, level of use, and existing deficiencies or details that may cause premature/aggravated deterioration.

A survey was conducted in 1990 of parking facility owners regarding costs of maintaining new and existing parking structures.⁵ Based on the survey, the average annual maintenance cost for a new structure and a 20-year-old structure are shown in Tables 1 and 2, respectively. The tables also list

TABLE 1: ANNUAL MAINTENANCE COST OF A NEW FACILITY⁵

Item Description	Quantity	Construction Cast-in-place		Age 0 Time	Cars 1000 \$/car/Yr	SF 320,000 \$/SF/Yr
		Unit Price	Total Cost			
Preventive Maintenance						
Sealants Floor Slab	10,000	3.00		10	3	0.01
Architectural Sealants	2,600	3.50	9,000	12	1	0.00
Expansion Joints	96	80.00	8,000	10	1	0.00
Penetrating Sealer	256,000	0.50	128,000	5	26	0.08
Traffic Topping	-	2.25	-	15	0	0.00
Supplemental Drains & Piping	-	1800.00	-	25	0	0.00
Miscellaneous	-	-	-	-	-	-
Subtotal			175,000		\$31.00	\$0.09
Replacement Maintenance						
Replace Drainage System	320,000	0.65	208,000	25	8	0.03
Replace Lighting System	320,000	1.75	560,000	25	22	0.07
Replace Parking Revenue Control	320,000	0.32	102,000	6	17	0.05
Replace Signage	1	30,000	30,000	25	1	0.00
Replace Elevators	2	120,000	240,000	25	10	0.03
Miscellaneous	-	-	-	-	-	-
Subtotal			1,140,000		\$58.00	\$0.18
Routine Maintenance						
Maintain Joint Sealants	1	1,500	2,000	1	2	0.01
Maintain Traffic Topping	-	-	-	1	0	0.00
Interim Slab Patching	-	-	-	1	0	0.00
Interim Beam & Column Patching	-	-	-	1	0	0.00
Stairtower Maintenance	1	2,000	2,000	1	2	0.01
Maintain Drainage System	1	1,000	1,000	1	1	0.00
Maintain Lighting	1	6,000	6,000	1	6	0.02
Maintain Parking/Revenue Control	1	2,000	2,000	1	2	0.01
Annual Inspections	1	5,000	5,000	3	2	0.01
Maintain Elevators	12	500	6,000	1	6	0.02
Miscellaneous	1	2,000	2,000	1	2	0.01
Sweeping/Cleaning	12	1,000	12,000	1	12	0.04
Power Wash Floors	4	2,000	8,000	1	8	0.03
Painting	1	10,000	10,000	1	10	0.03
Subtotal			56,000		\$53.00	\$0.19
Average Annual Maintenance Cost					\$142.00	\$0.46

Based on 1990 Survey

TABLE 2: ANNUAL MAINTENANCE COST OF A 20-YEAR-OLD FACILITY⁵

Item Description	Quantity	Construction Cast-in-place		Age 20 Time	Cars 1000 \$/car/Yr	SF 320,000 \$/SF/Yr
		Unit Price	Total Cost			
Preventive Maintenance						
Sealants Floor Slab	10,000	3.00	30,000	10	3	0.01
Architectural Sealants	2,600	3.50	9,000	12	1	0.00
Expansion Joints	96	80.00	8,000	10	1	0.00
Penetrating Sealer	-	0.50	-	5	0	0.00
Traffic Topping	256,000	2.25	576,000	15	38	0.12
Supplemental Drains & Piping	10	1800.00	18,000	25	1	0.00
Miscellaneous	1	50,000	50,000	10	5	0.02
Subtotal					\$49.00	\$0.15
Replacement Maintenance						
Replace Drainage System	320,000	0.65	208,000	25	8	0.03
Replace Lighting System	320,000	1.75	560,000	25	22	0.07
Replace Parking Revenue Control	320,000	0.32	102,000	6	17	0.05
Replace Signage	1	30,000	30,000	25	1	0.00
Replace Elevators	2	120,000	240,000	25	10	0.03
Miscellaneous	-	-	-	-	-	-
Subtotal					\$58.00	\$0.18
Routine Maintenance						
Maintain Joint Sealants	1	1,500	2,000	1	2	0.01
Maintain Traffic Topping	1	2,000	2,000	1	2	0.01
Interim Slab Patching	1	3,000	3,000	1	3	0.01
Interim Beam & Column Patching	1	2,000	2,000	1	2	0.01
Stairtower Maintenance	1	2,000	2,000	1	2	0.01
Maintain Drainage System	1	1,000	1,000	1	1	0.00
Maintain Lighting	1	6,000	6,000	1	6	0.02
Maintain Parking/Revenue Control	1	2,000	2,000	1	2	0.01
Annual Inspections	1	7,000	7,000	1	7	0.02
Maintain Elevators	12	1,000	12,000	1	12	0.04
Miscellaneous	1	4,000	4,000	1	4	0.01
Sweeping/Cleaning	12	1,000	12,000	1	12	0.04
Power Wash Floors	4	2,000	8,000	1	8	0.03
Painting	1	10,000	10,000	1	10	0.03
Subtotal					\$73.00	\$0.25
Average Annual Maintenance Cost					\$180.00	\$0.58

Based on 1990 Survey

common items that are included in a maintenance program. In addition to routine and preventive maintenance, the tables have a listing for “replacement maintenance.” Replacement maintenance is defined as the replacement cost of items that have reached the end of their service life or have become obsolete and need to be upgraded. These include revenue collection systems, drainage systems, lighting systems, elevators, and signage. Surveys can be used as a guide in budgeting maintenance cost and developing the asset management plan for parking structures.

The average maintenance cost for a new parking structure is approximately \$0.46/ft² (\$4.95/m²)/year (\$142/parking space/year) and the average maintenance cost for a 20-year-old parking structure is approximately \$0.58/ft² (\$6.24/m²)/year (\$180/parking space/year) in 1990 dollars. Although the data was collected in the 1990s, the tables provide a template of expected costs for items to be included in the maintenance program. The information in the tables can be modified by owners and operators based on the type of structure, use, climatic conditions, and cost data from similar projects in the local vicinity to develop annual maintenance budgets. The Airport Cooperative Research Program (ACRP) Synthesis 47⁶ provides more detailed guidance and discussion on developing an annual asset management program.

Parking structures are a significant part of an owner’s real estate portfolio. Owners and operators need to recognize this and develop a comprehensive asset management plan that includes routine and preventative maintenance and structural repairs, rehabilitation, and restoration to extend the anticipated service life and minimize overall maintenance cost. Simple effective strategies discussed in this article can be used to keep an eye out for problems and address them through an effective inspection and maintenance program. This will prevent small problems from becoming causes for large repair bills and will reduce the overall life-cycle maintenance cost of the structure.

REFERENCES

1. National Parking Association, *Parking Garage Maintenance Manual*, fourth edition, Washington, DC, 2004, 111 pp.
2. Precast Concrete Institute (PCI), *Maintenance Manual for Precast Parking Structures*, Chicago, IL, 2004, 24 pp.
3. ACI Committee 362, “Guide for Structural Maintenance of Parking Structures (ACI 362.2R-00) (Reapproved 2013),” American Concrete Institute, Farmington Hills, MI, 2013, 15 pp.

4. ACI Committee 364, “Guide for Evaluation of Concrete Structures before Rehabilitation (ACI 364.1R-07),” American Concrete Institute, Farmington Hills, MI, 2007, 18 pp.

5. Chrest, A. P.; Smith, M. S.; Bhuyan, S.; Monahan, D. R.; and Iqbal, M., *Parking Structures: Planning, Design, Construction, Maintenance and Repair*, third edition, Kluwer Academic Publishers, Dordrecht, the Netherlands, 2000, 856 pp.

6. Shiu, K. N.; Salm, K. L.; and Beckstorm, J., “ACRP Synthesis 47, Repairing and Maintaining Airport Parking Structures While in Use,” Washington, DC, 2013, 56 pp.



Pawan R. Gupta is a Senior Restoration Project Manager at Walker Restoration Consultants in Los Angeles, CA. He has been involved in the design, repair, and rehabilitation of post-tensioned facilities in the United States and Canada for the last 15 years. He

received his PhD from the University of Toronto, Toronto, ON, Canada, and is active in several professional organizations, including ACI and ICRI. He is a member of ICRI Committee 150, ICRI Notes on ACI 562 Code Requirements. He is a Fellow of ACI and a member of ACI Committees 350, Environmental Engineering Concrete Structures; 364, Rehabilitation; 437, Strength Evaluation of Existing Concrete Structures; and 440, Fiber-Reinforced Polymer Reinforcement, and Joint ACI-ASCE Committee 423, Prestressed Concrete.



K. Nam Shiu is a Senior Vice President with Walker Restoration Consultants, a Division of Walker Parking Consultants. He has over 35 years of investigative and forensic experience identifying contributing causes of noted distresses and construction-related

structural, material, and waterproofing defects. His clients include building owners, property management companies, insurance companies, healthcare facilities, and government agencies. Shiu has worked with façade and curtain wall evaluations, building leakage evaluations, distress investigation, expert witnessing, and repair design for corrosion-related deterioration. Shiu is on the Direction Board of the Strategic Development Council of ACI and Chairs the Vision 2020 Concrete Repair Council. He is a Fellow of ACI and ASCE and actively participates in a number of ACI technical committees. He is also a member of ICRI.